TESTING OF A LOOP HEAT PIPE SUBJECTED TO VARIABLE ACCELERATING FORCES

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Outline

- Objective
- Test Article
- Test Setup
- Test Configurations
- Spin Patterns (Variable Accelerations)
- Model Profile
- Overview of Test Results
- Effects of Accelerations on LHP Operation
  - Start-up
  - Operating temperature
  - Temperature Oscillation
  - Temperature Hysteresis
- Conclusions

Objectives

- Investigate the functionality of an LHP when subjected to variable accelerating forces.
  - Continuous spin
  - Periodic spin
  - Direction of applied force
- Investigate effects of accelerating forces on loop operation.
  - Start-up
  - Operating temperature
  - Temperature oscillation
  - Temperature hysteresis

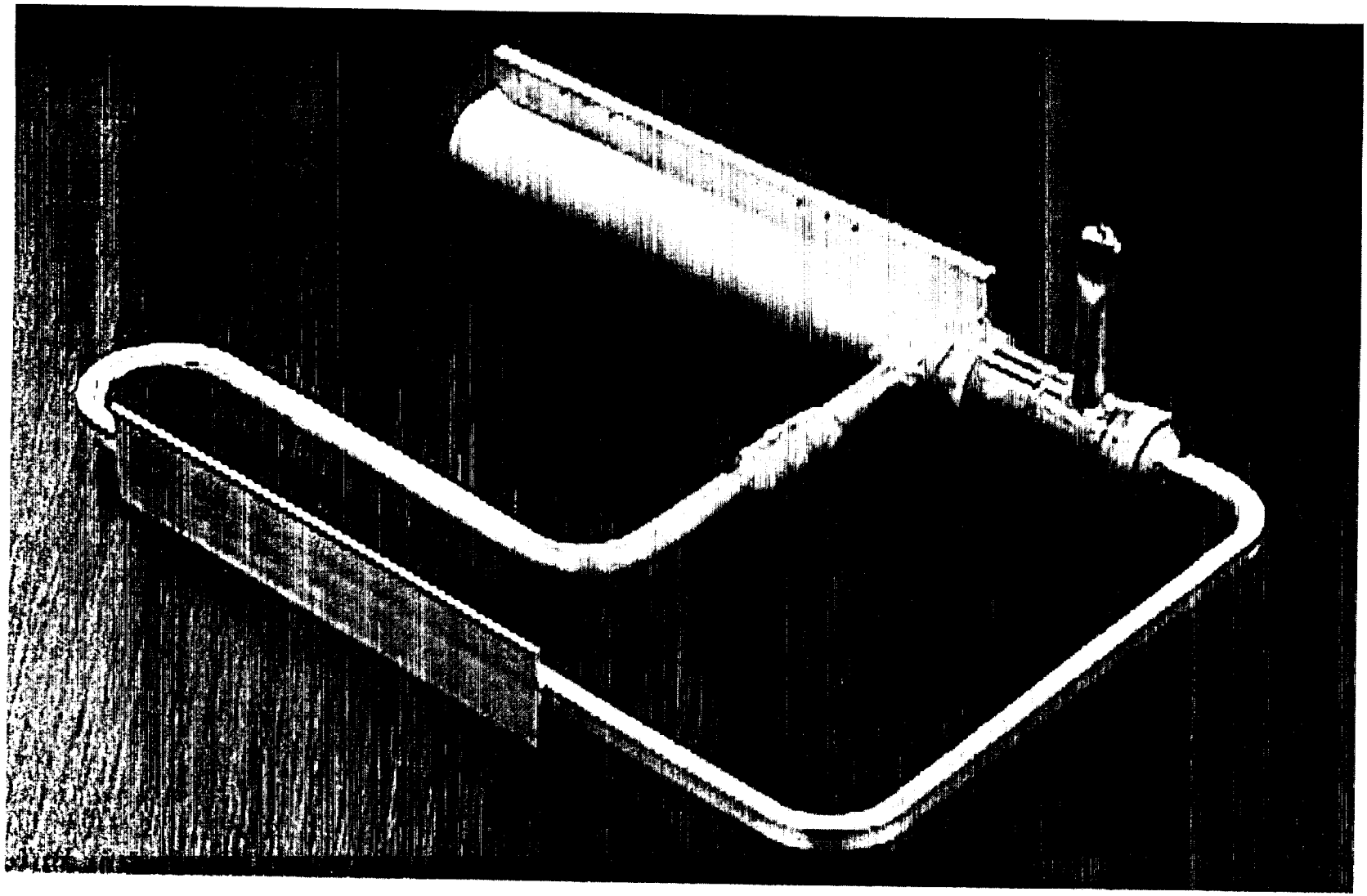
Summary of LHP Design Parameters
1 of 2

- Evaporator
  - Envelope
    - » Aluminum 6063
    - » OD: 13mm, ID: 10 mm, length: 120 mm
  - Primary Wick
    - » Sintered nickel
    - » OD: 10mm, ID: 4mm, length: 120mm
    - » Pore Size: ~1.2 microns
    - » Permeability: 4×10^{-14} m^2
    - » Porosity: 60%
  - Longitudinal and circumferential grooves
- Condenser
  - Aluminum 6063 extrusion
  - OD: 12mm, ID: 2.8mm, length: 100 mm

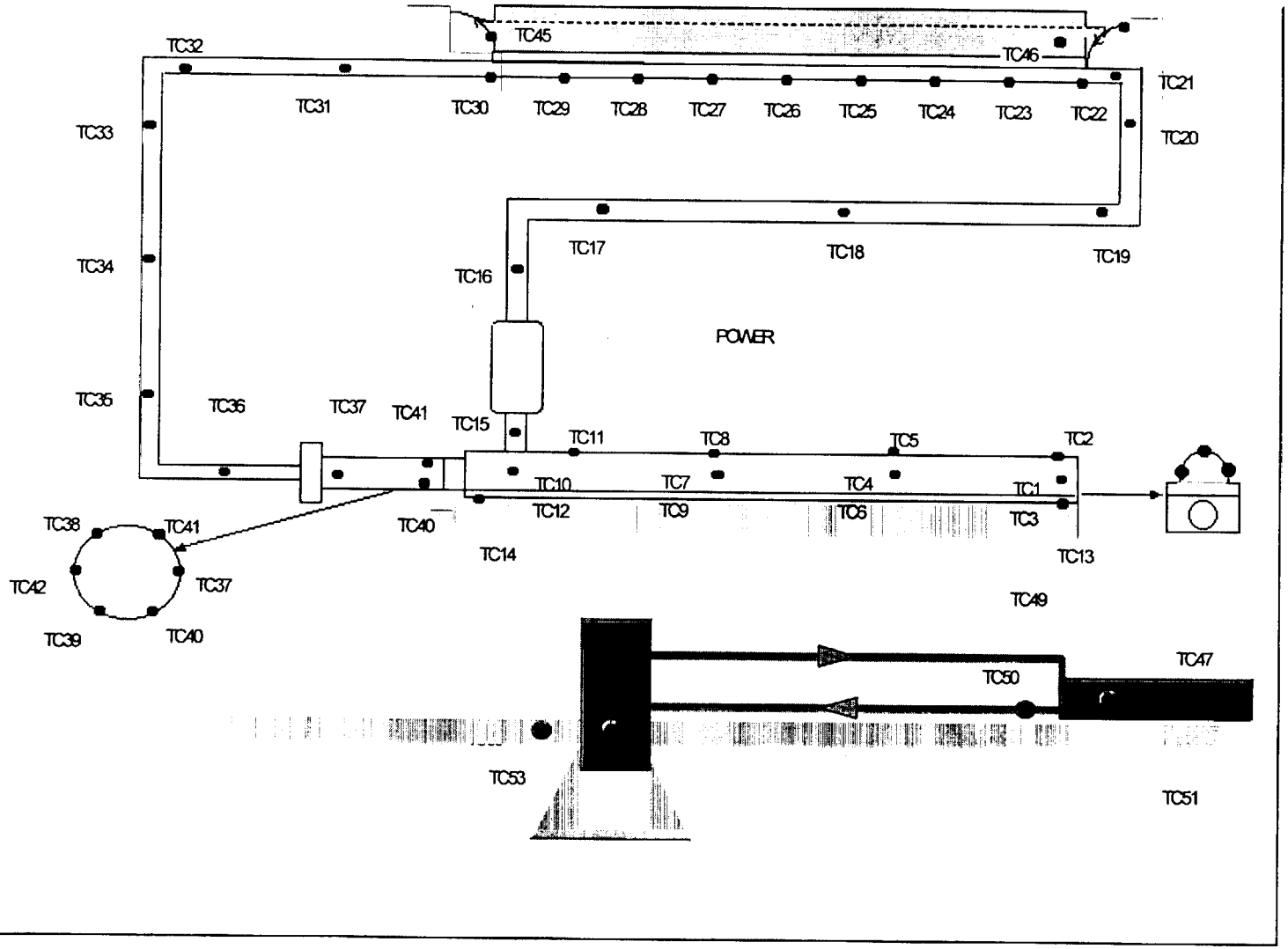
Summary of LHP Design Parameters
2 of 2

- Compensation Chamber
  - Envelope
    - » Aluminum 6061/stainless steel 304L bimetallic
    - » OD: 13mm, ID: 10mm, length: 50mm
  - Secondary wick
    - » Stainless steel screen
    - » 250 x 1400 mesh
    - » Pore size: 15.4 microns
- Vapor Line
  - Aluminum 6063 extrusion
  - OD: 12mm, ID: 2.8mm, length: 160 mm
- Liquid Line
  - Aluminum 6063 extrusion
  - OD: 12mm, ID: 2.8mm, length: 130 mm

Picture of the LHP



Schematic of Test Setup



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Test Configurations

- Loop Orientations in Stationary Tests
  - Horizontal
  - Vertical with CC above evaporator
  - Vertical with evaporator above CC
- Loop Orientation with Acceleration
  - Evaporator/CC parallel to accelerating force with CC on outer edge
  - Evaporator/CC parallel to accelerating force with evap. on outer edge
  - Clockwise (CW) or counterclockwise (CCW) spin
- Continuous Acceleration
  - Spin rates: 30 rpm (1.2G's) or 60 rpm (4.7 G's)
  - Combinations of 30 rpm and 60 rpm
- Periodic Acceleration Patterns
  - 0 rpm/30 rpm/0rpm (300 sec/30 sec/300 sec)
  - 0 rpm/60 rpm/0 rpm (300 sec/30 sec/300 sec)
  - 0 rpm/30 rpm/0 rpm/60 rpm (300 sec/30 sec/300 sec/30 sec)
  - "Random" spin

Test Profiles

- Start-up with various heat loads, sink temperatures and spin patterns
- Operation with variable powers and constant sink temperatures
- Operation with variable sink temperature and constant powers
- Model profile
  - Start-up with 25W heat load and 0 °C sink temperature
  - Power cycle: 25W/100W/25W/100W (sink at 0 °C)
  - Sink temperature cycle: 0 °C/-40 °C/0 °C (power at 100W)
  - Steady state at each step
- Operation with model profile and various spin patterns

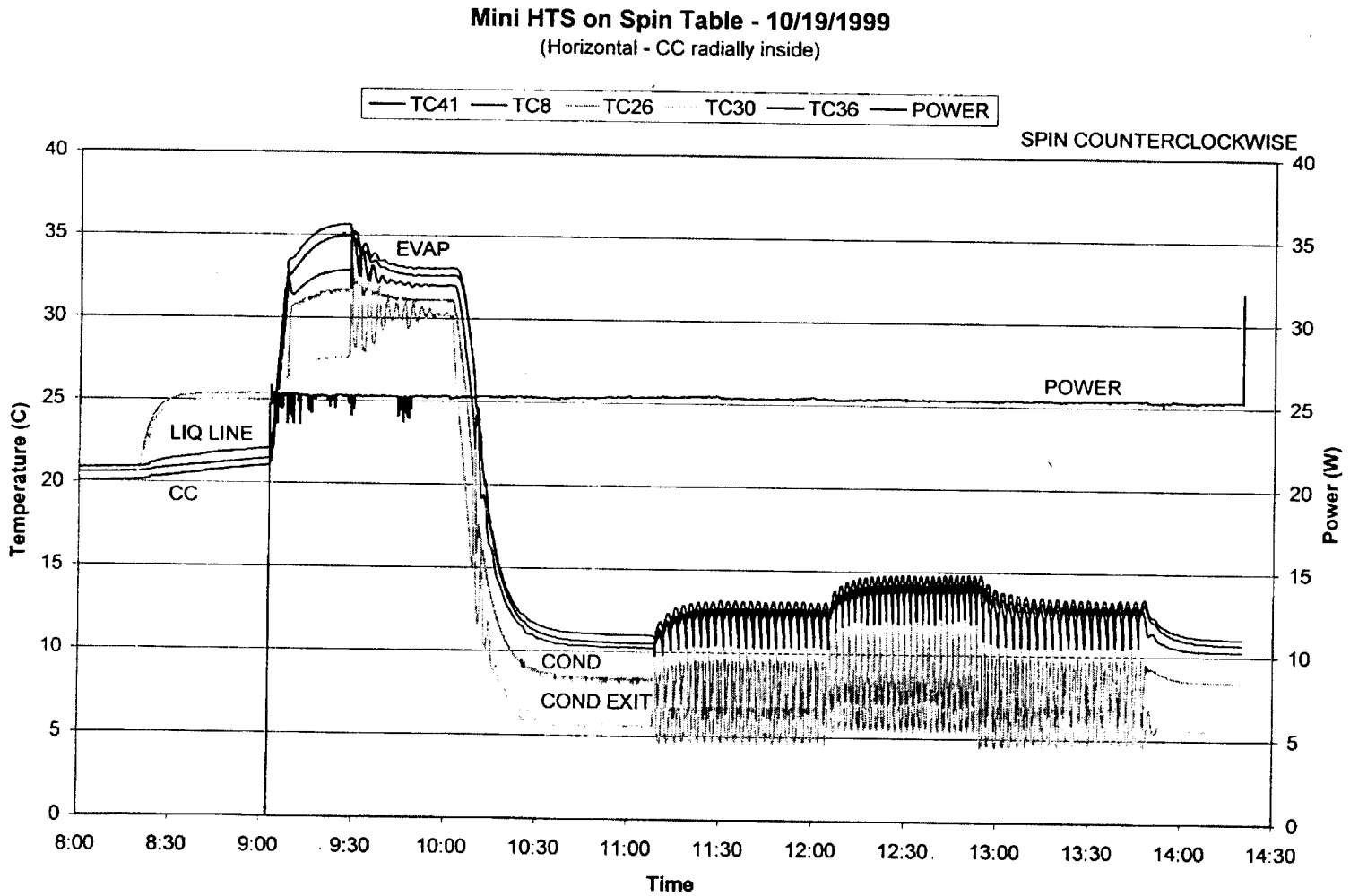
Overview of Test Results

- More than 50 tests were performed.
- The LHP operated properly without a deprime for all test conditions.
- The loop operating temperature under stationary tests is a function of the heat load and the sink temperature.
- The acceleration affects the loop operating temperature through its influences on the fluid distribution within the evaporator, condenser and CC.
- The effects on the loop operating temperature due to acceleration is superimposed upon the effects due to heat load and sink temperature.
  - Continuous acceleration leads to steady or quasi-steady operation.
  - Periodic acceleration leads to quasi-steady operation.
- Depending on the operating conditions and the loop orientation, the acceleration may cause the operating temperature to increase or decrease, and may cause a temperature overshoot during start-up or temperature oscillation/hysteresis during normal operation.

Start-up

- Start-up conditions
  - Power: 5W, 25W, 50W, 100W
  - Sink temperature: -20 °C, -10 °C, 0 °C, 10 °C, 20 °C
  - Variable spin rates and spin patterns
- Most start-ups showed little noticeable superheat or temperature overshoot.
- Spinning the LHP prior to start-up may cause a temperature overshoot as high as 45 °C!
- Temperature overshoot due to centrifugal forces (spinning) is similar to that due to the gravitational force in stationary tests.

Typical Start-up without Temperature Overshoot
25W/25C/0C (1 of 2)



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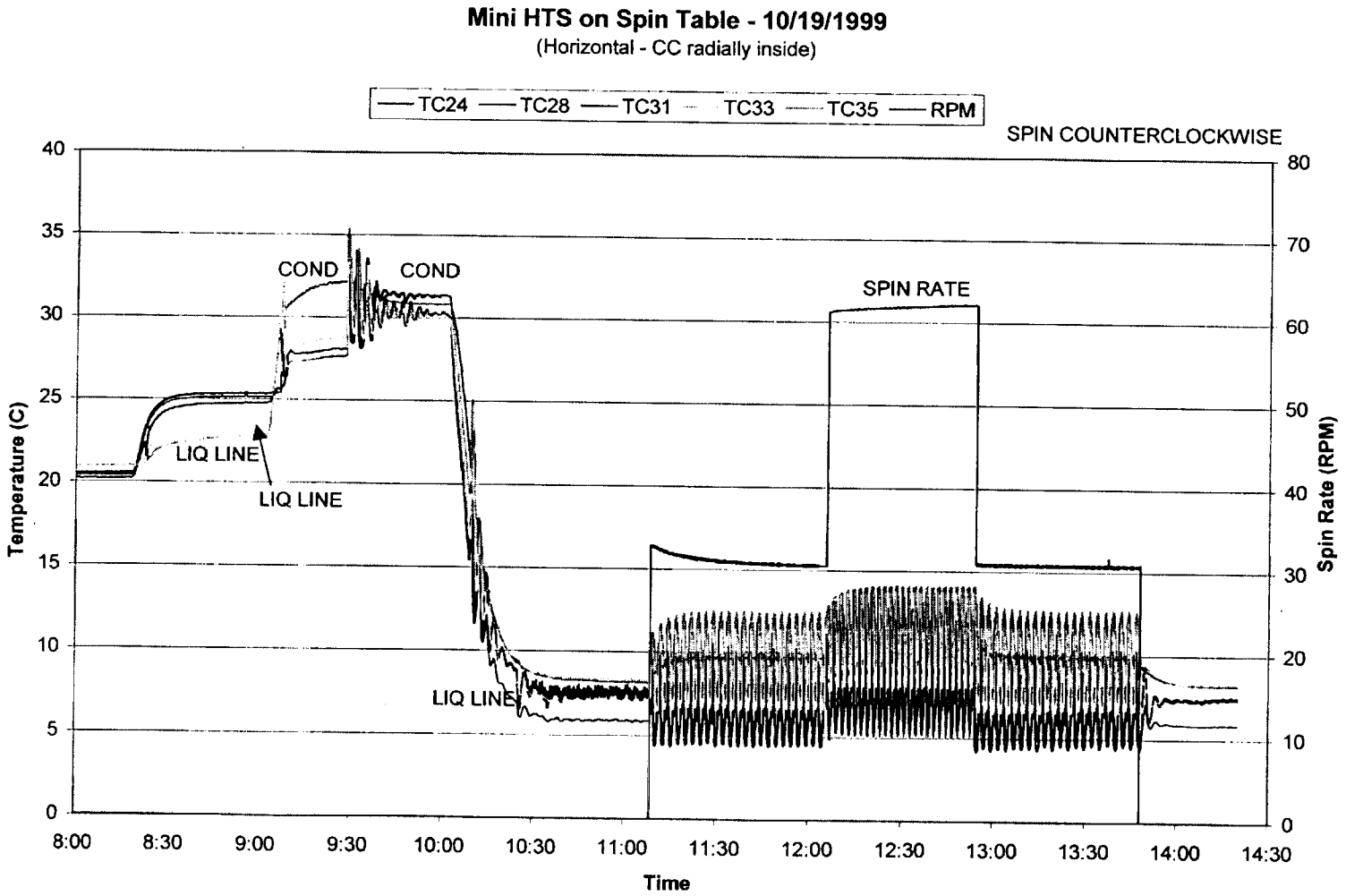
Typical Start-up without Temperature Overshoot
25W/25C/0C (2 of 2)



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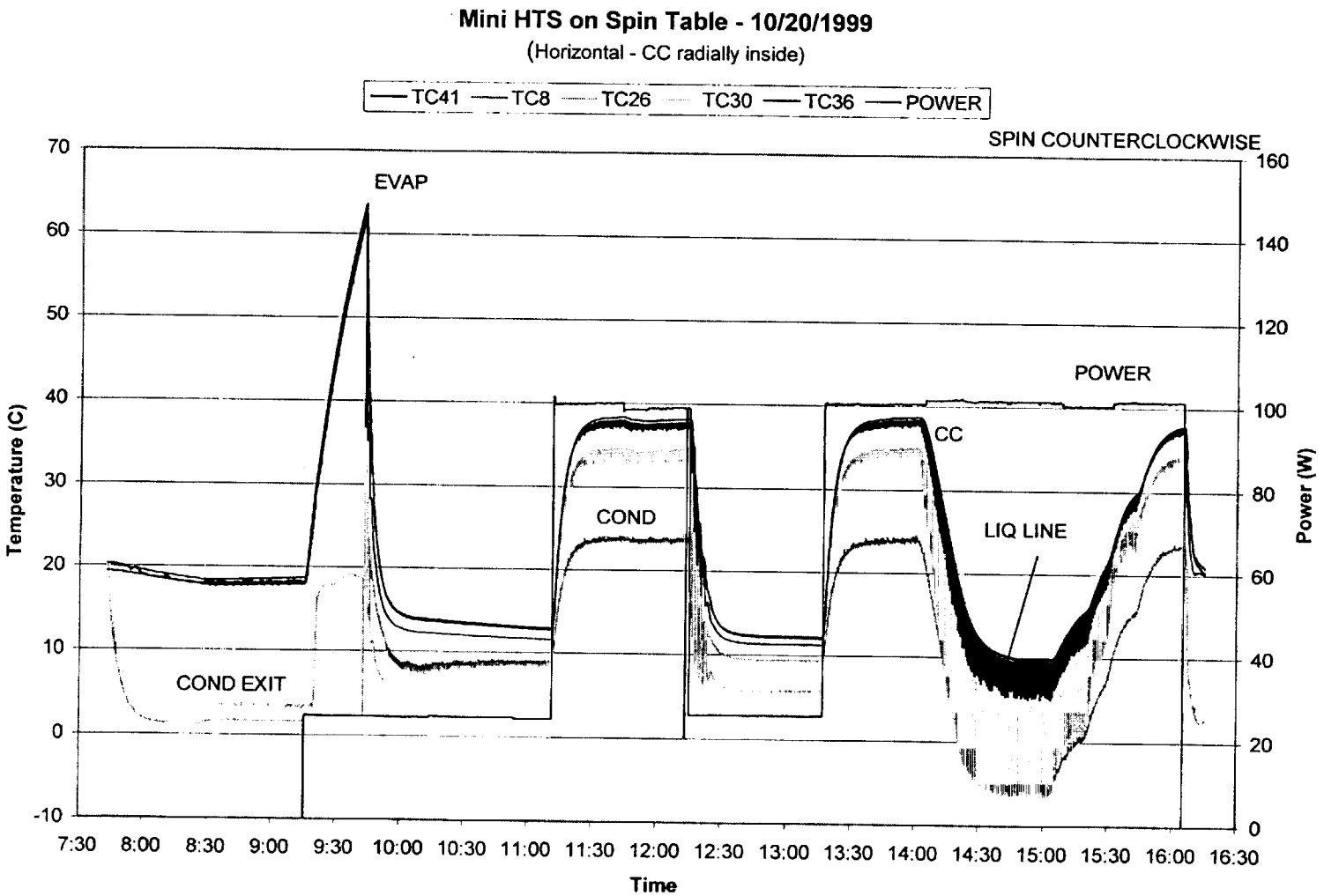
Start-up with a Large Temperature Overshoot

30rpm/model profile (1 of 2)



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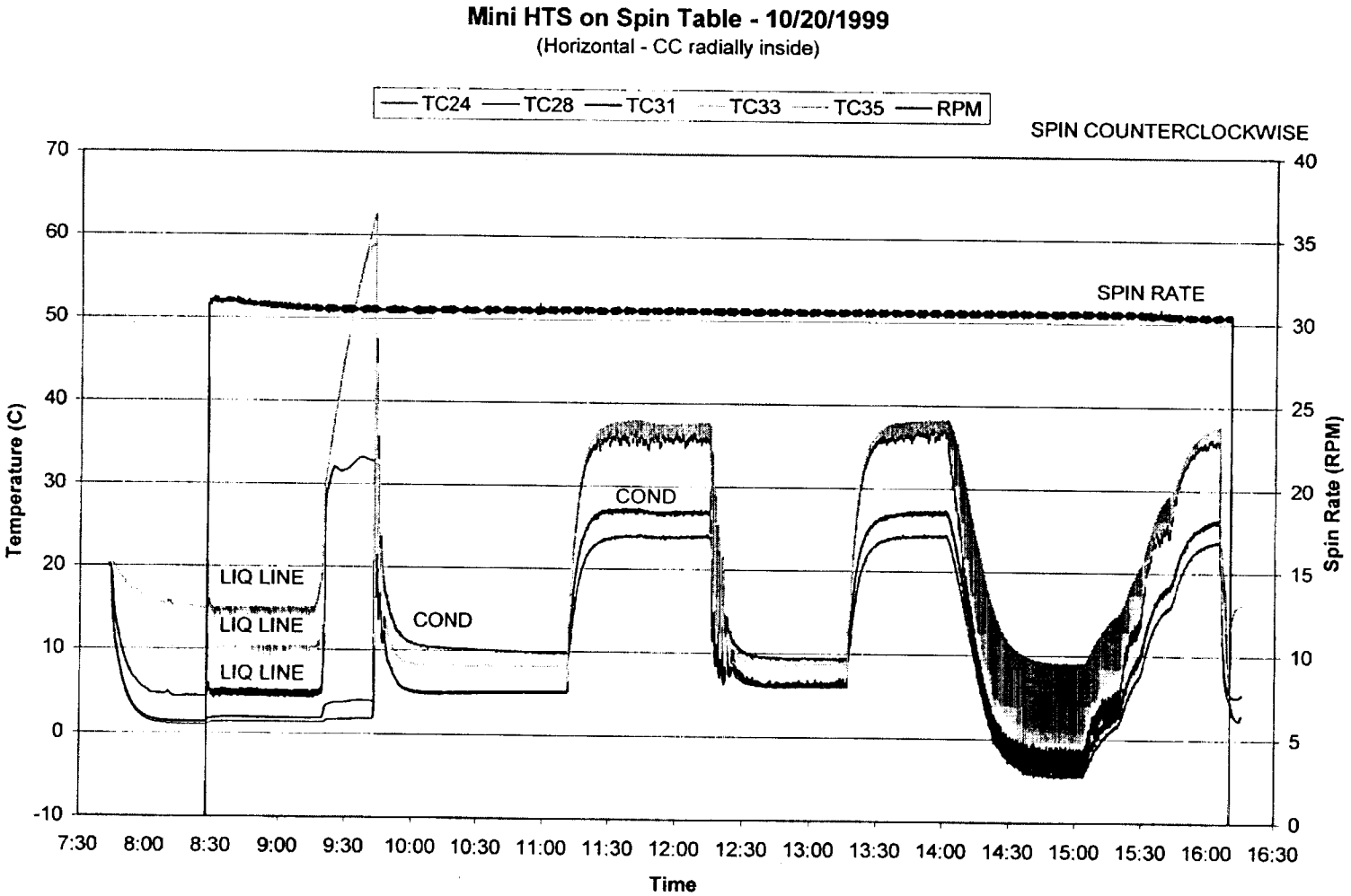
Start-up with a Large Temperature Overshoot
30 rpm/model profile (2 of 2)



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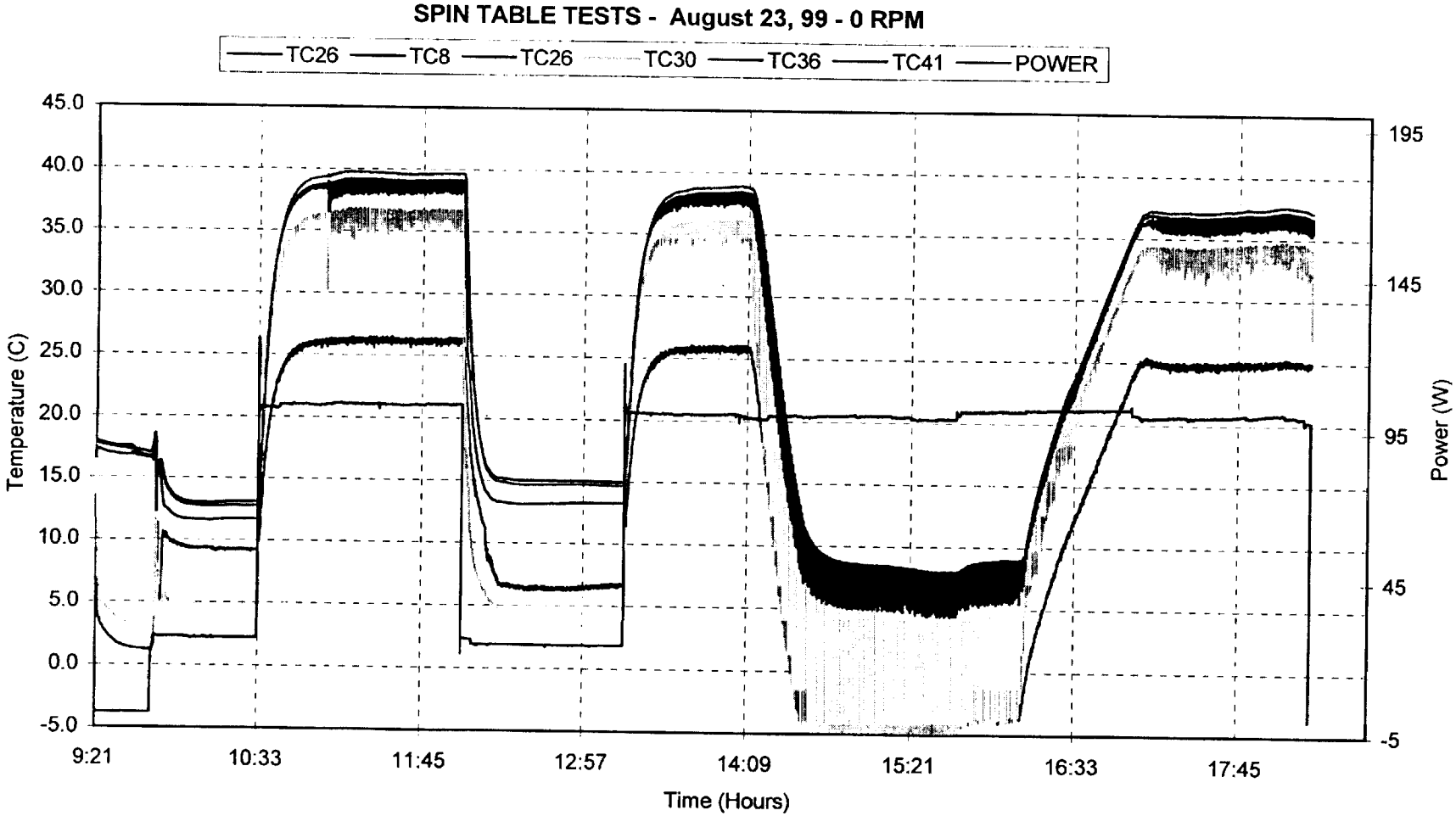
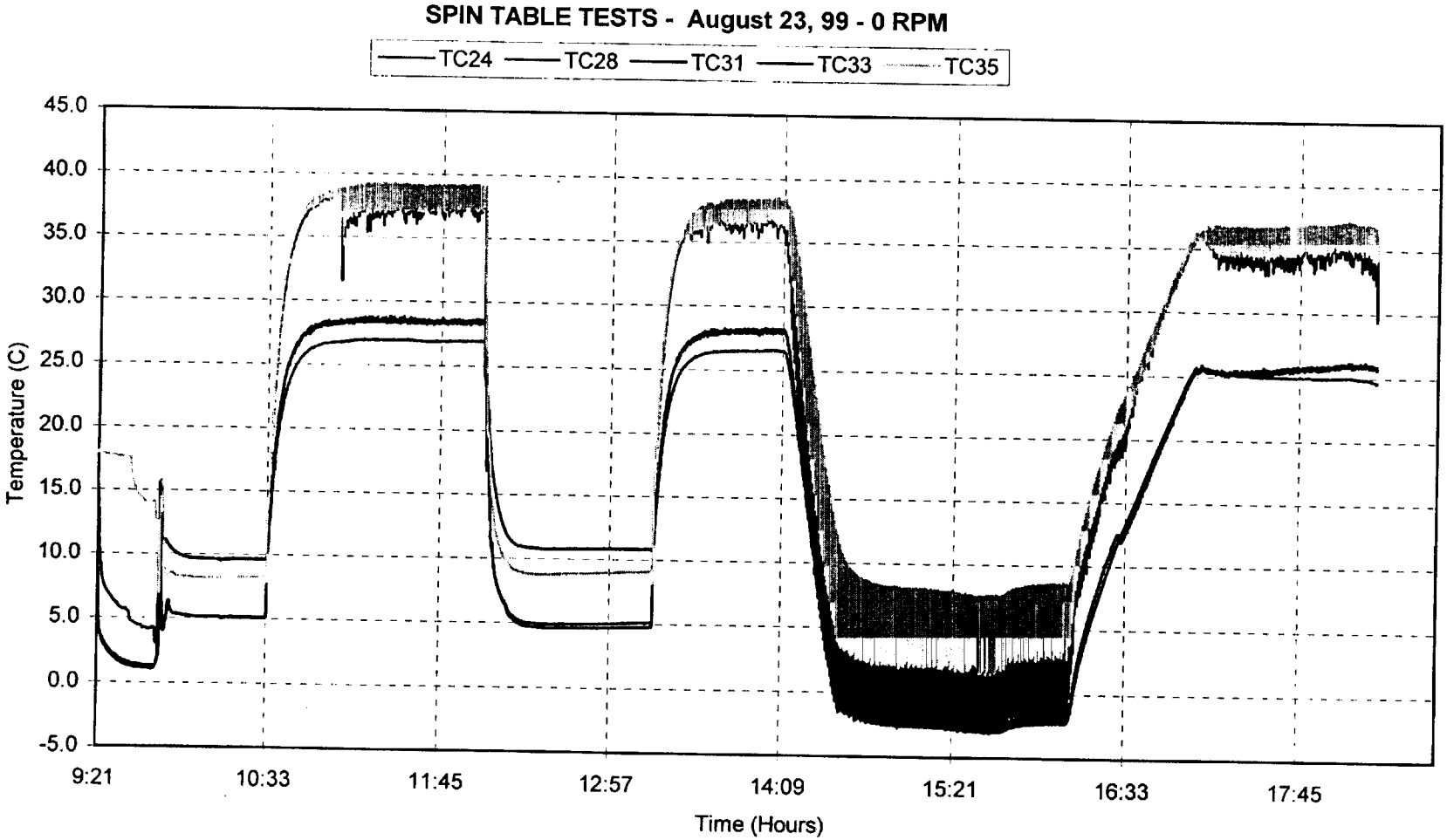
LHP Operation Under Stationary Condition

LHP Flat/Model Profile (1 of 2)



LHP Operation Under Stationary Condition
LHP Flat/Model Profile (2 of 2)



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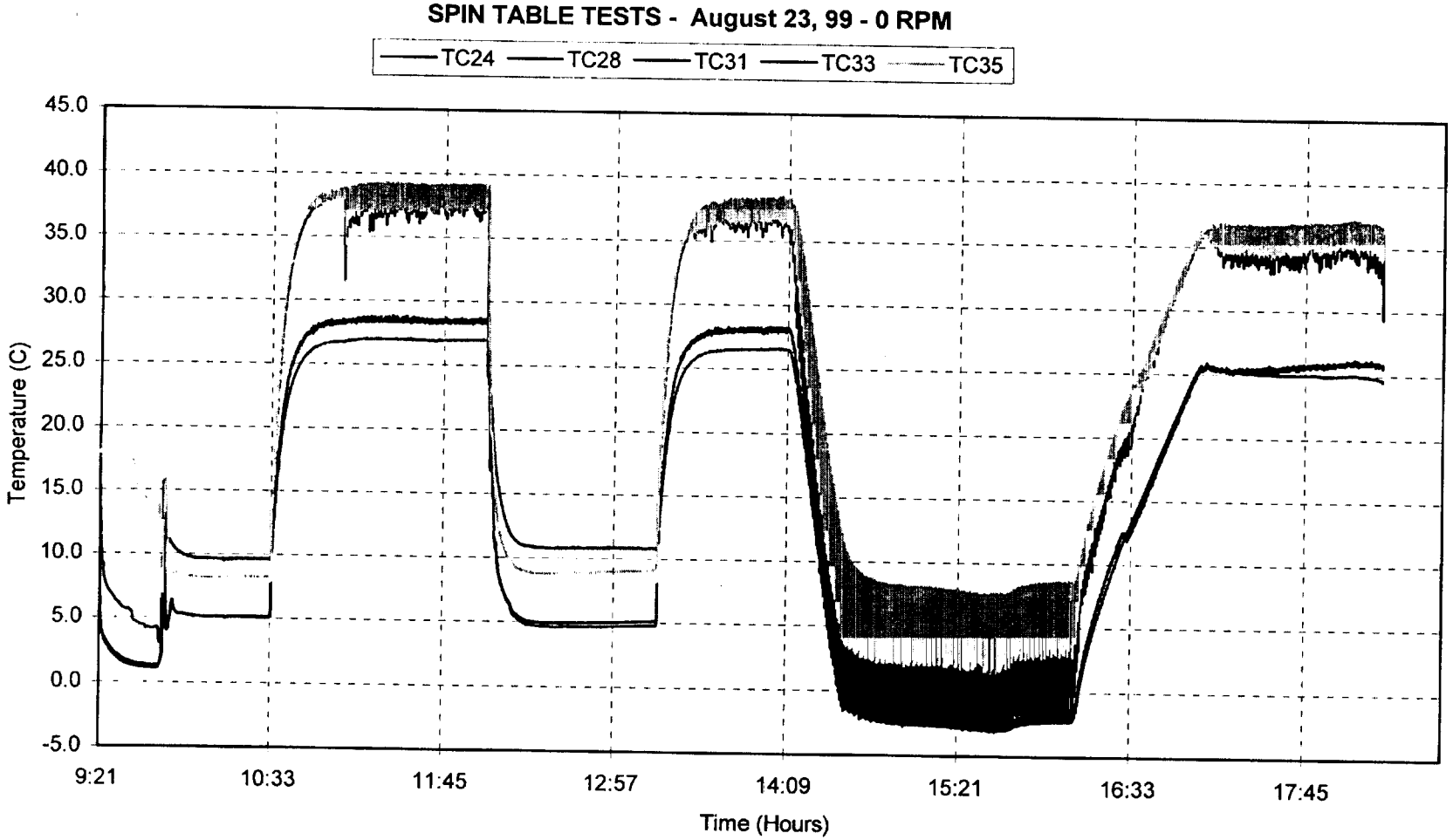
LHP Operation Under Stationary Condition

LHP Flat/Model Profile (2 of 2)



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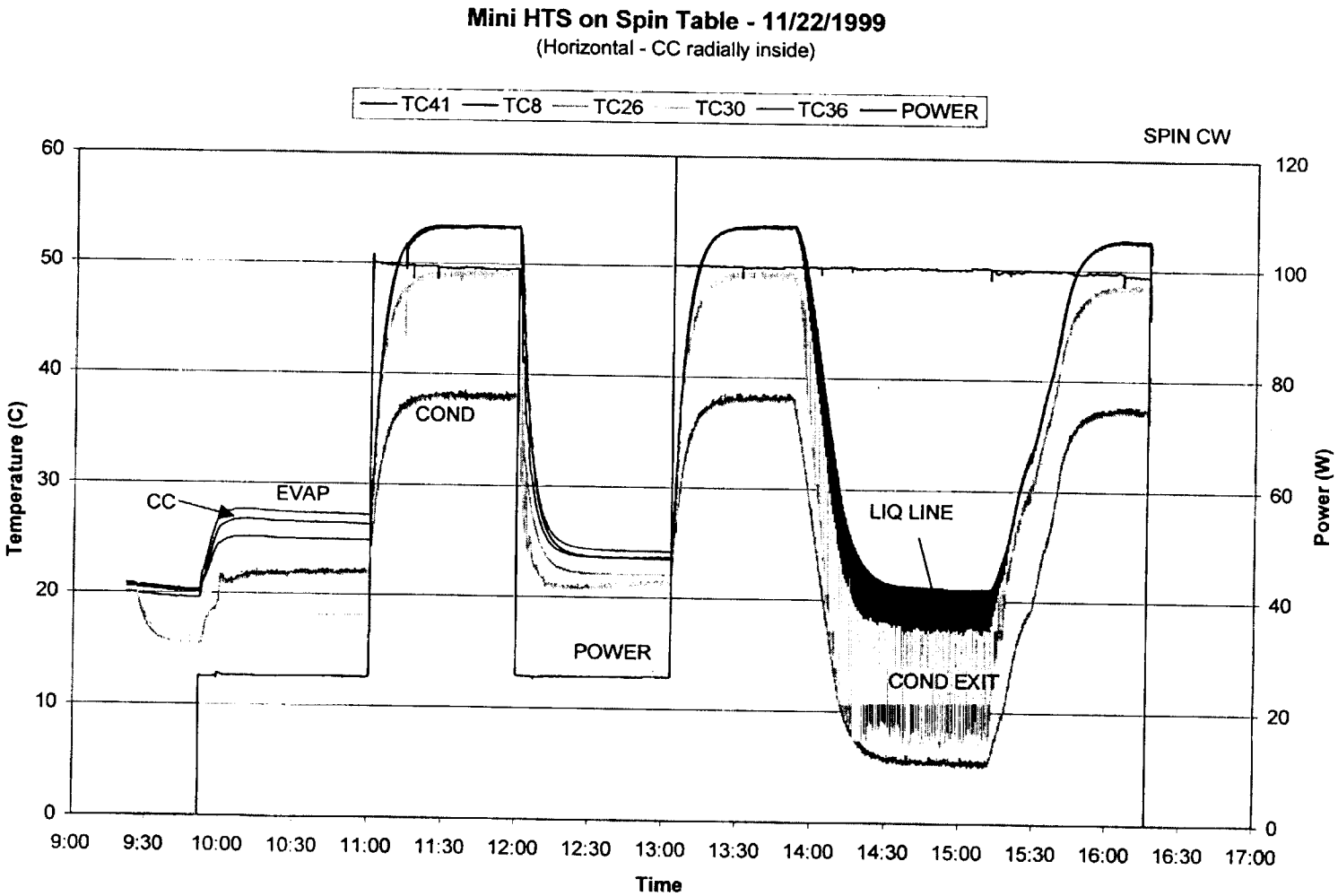
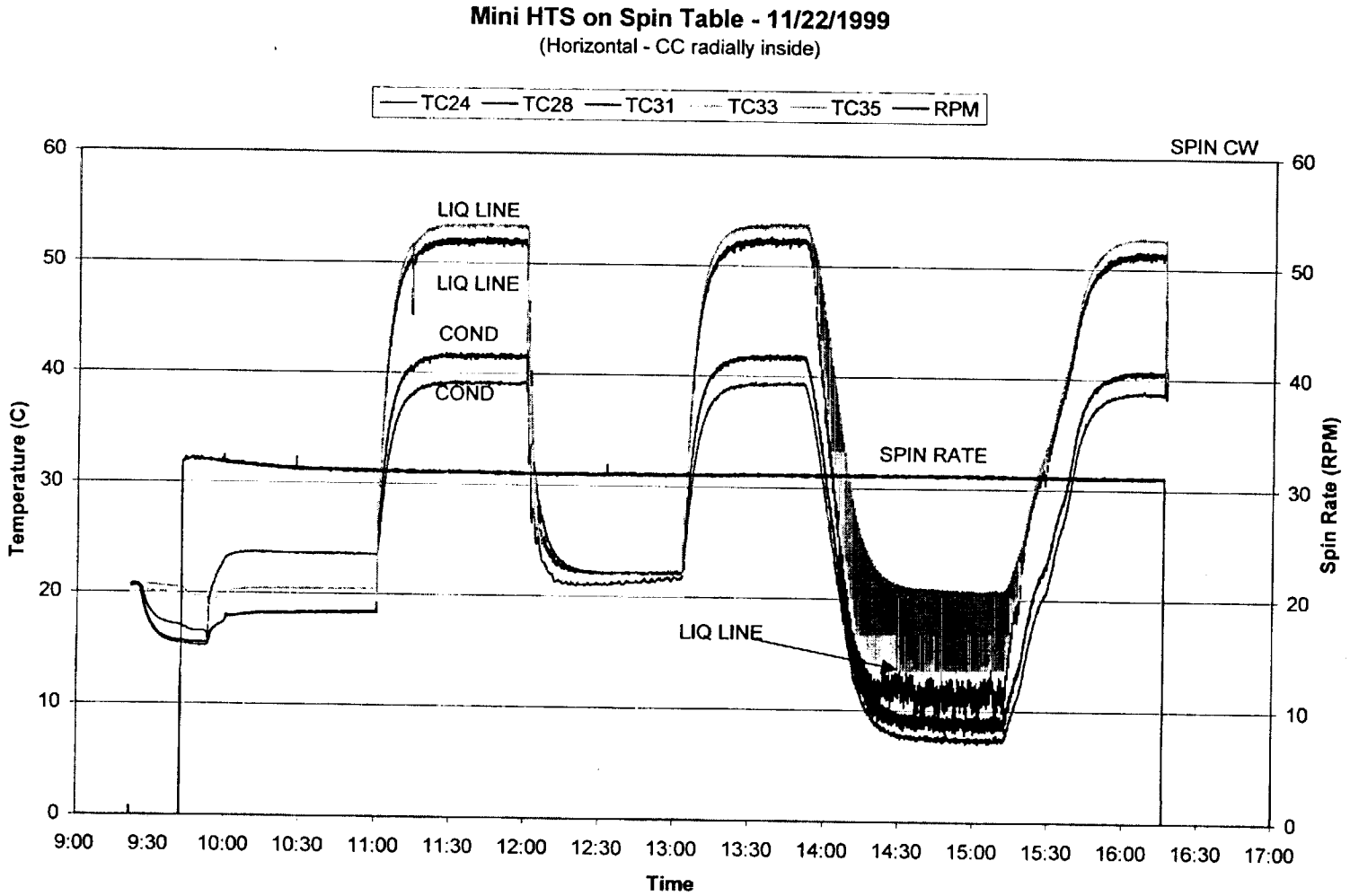
LHP Operation Under Continuous Acceleration

Evaporator on Outer Edge/CW Spin/30 rpm/Model Profile (1 of 2)



LHP Operation Under Continuous Acceleration
Evaporator on Outer Edge/CW Spin/30 rpm/Model Profile (2 of 2)



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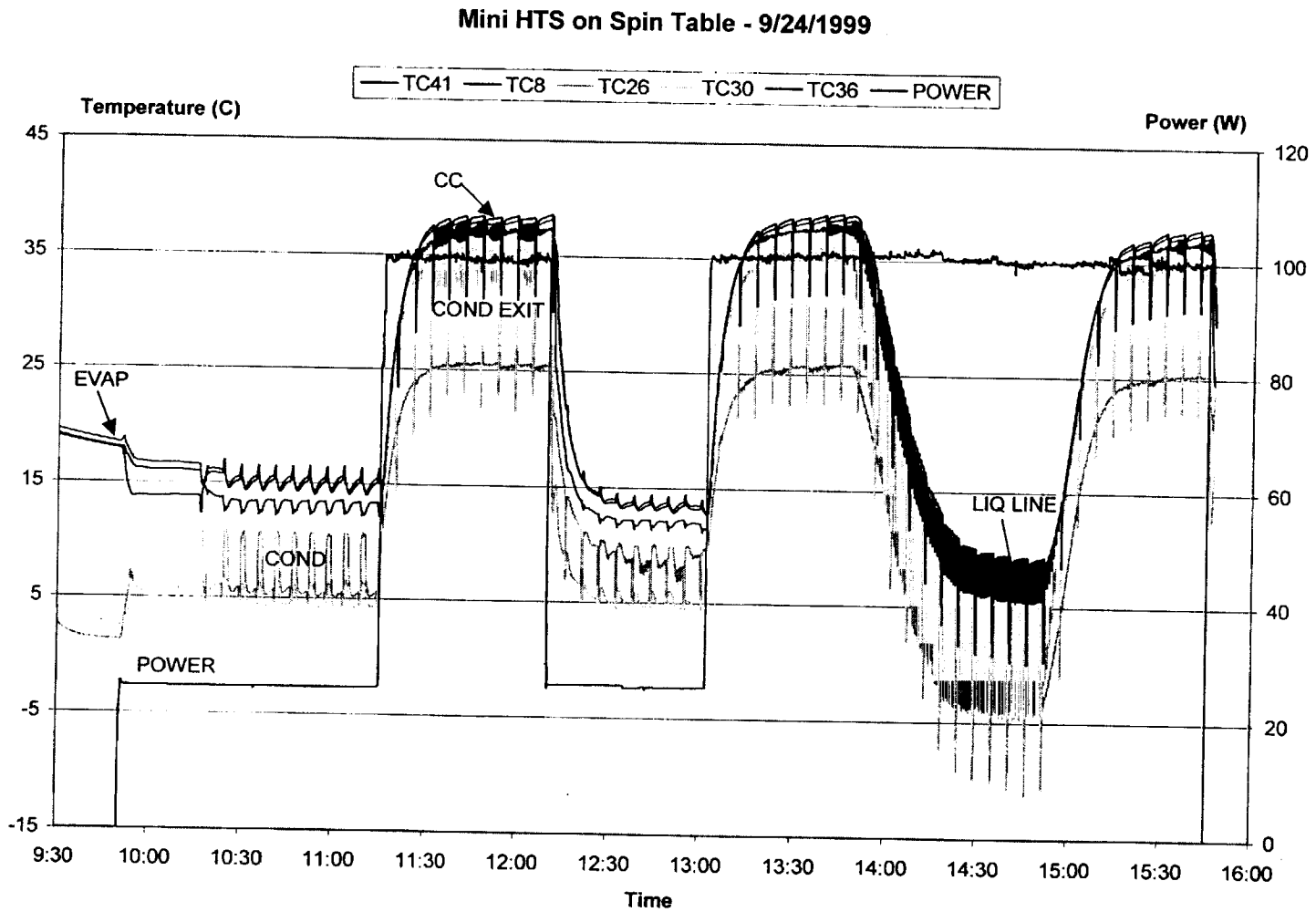
LHP Operation Under Periodic Acceleration

CC on Outer Edge/30rpm/0rpm/CCW Spin/Model Profile (1 of 2)



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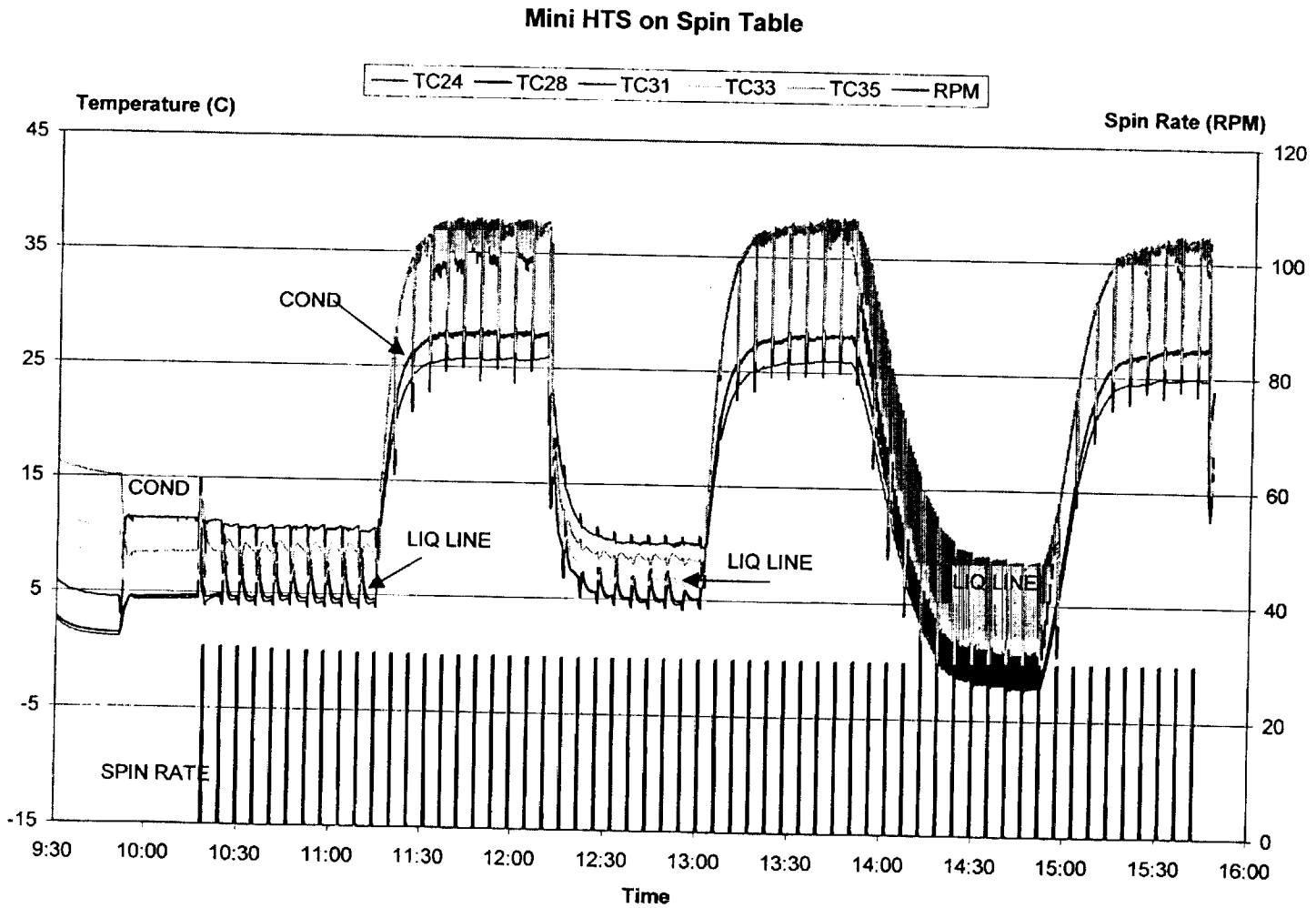
LHP Operation Under Periodic Acceleration
CC on Outer Edge/30rpm/0rpm/CCW Spin/Model Profile (2 of 2)



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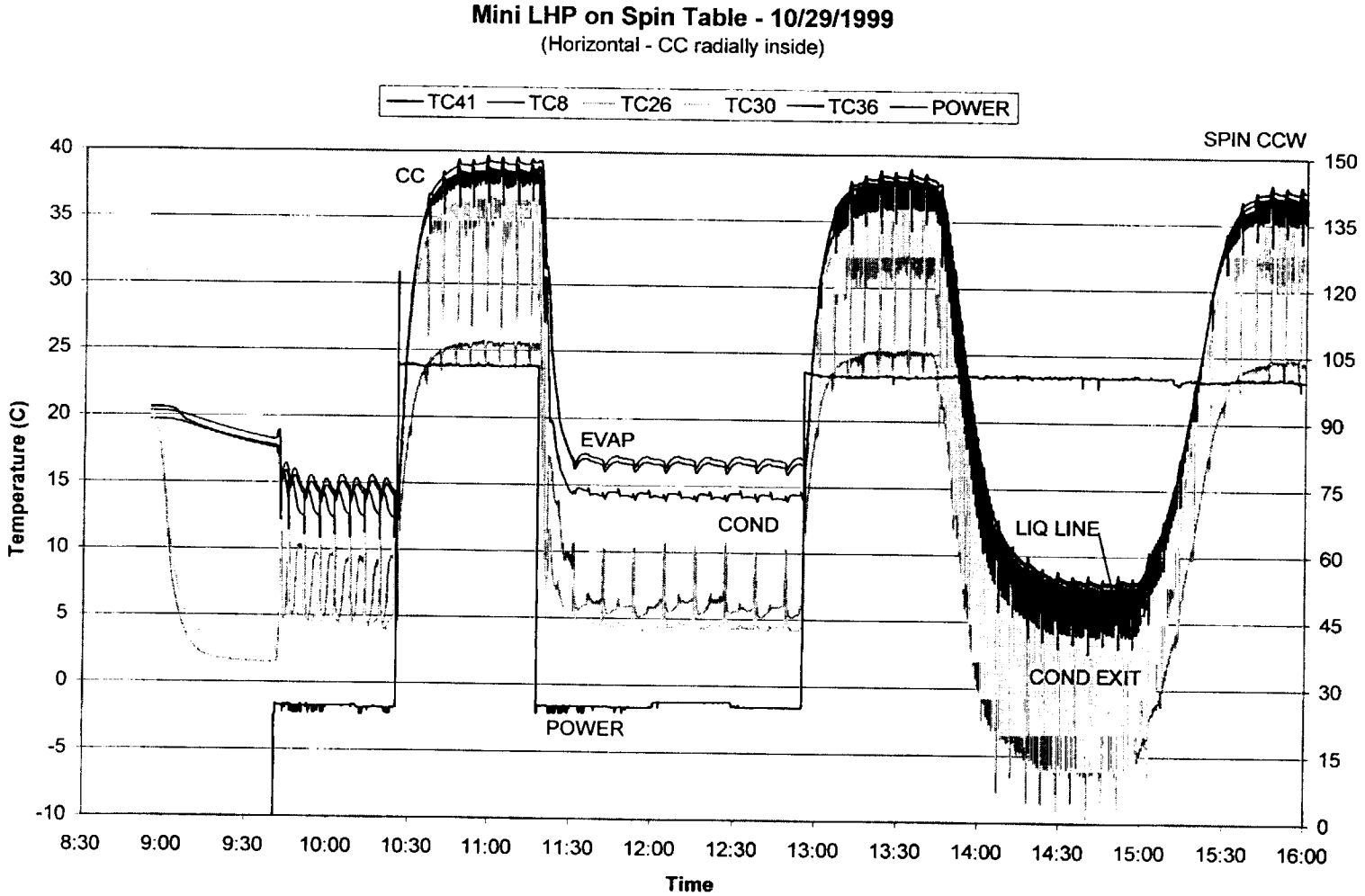
LHP Operation Under Periodic Acceleration
Evaporator on Outer Edge/30rpm/0rpm/60rpm/CCW/Model Profile



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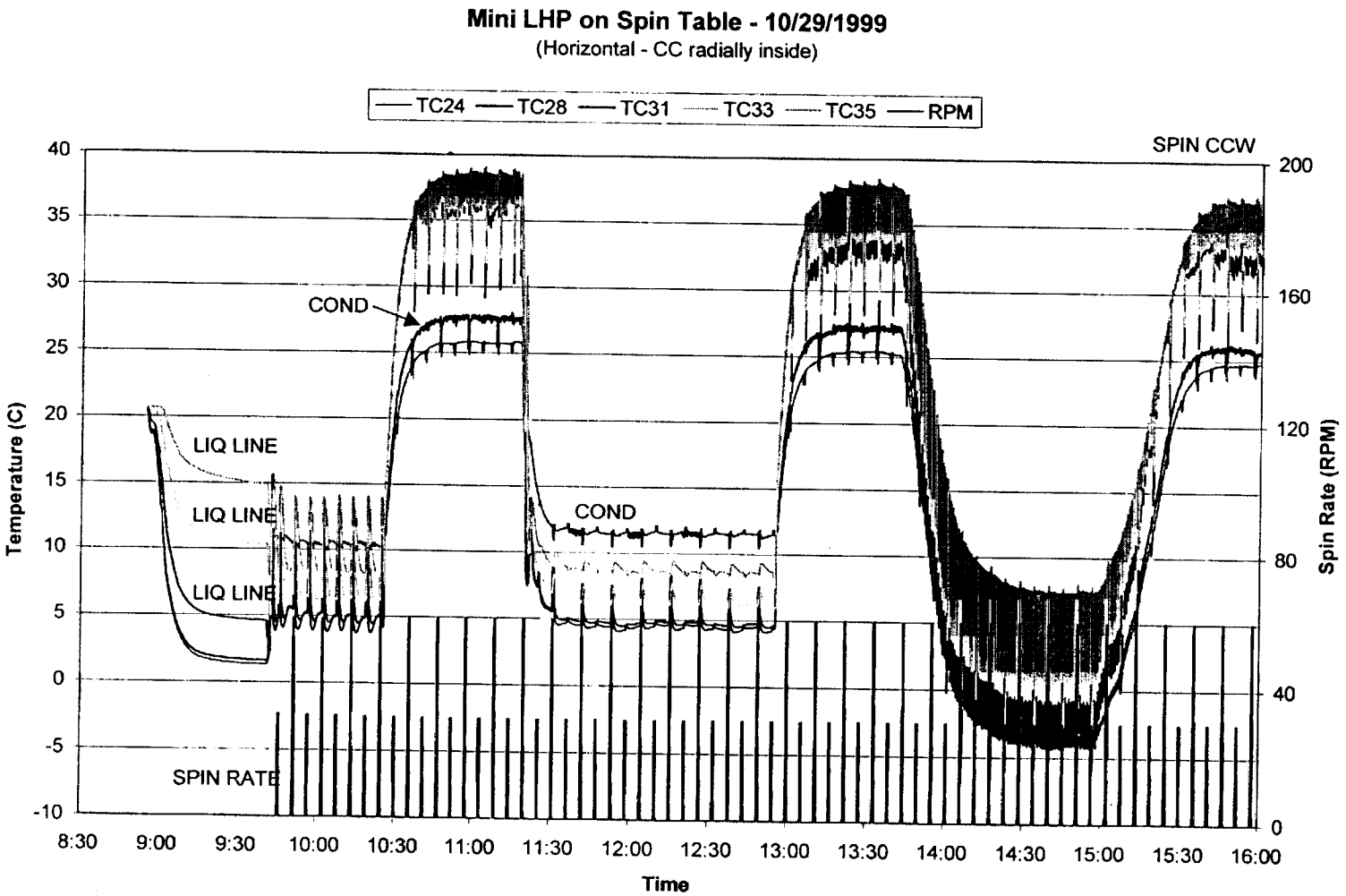
LHP Operation Under Periodic Acceleration

Evaporator on Outer Edge/30rpm/0rpm/60rpm/CCW/Model Profile



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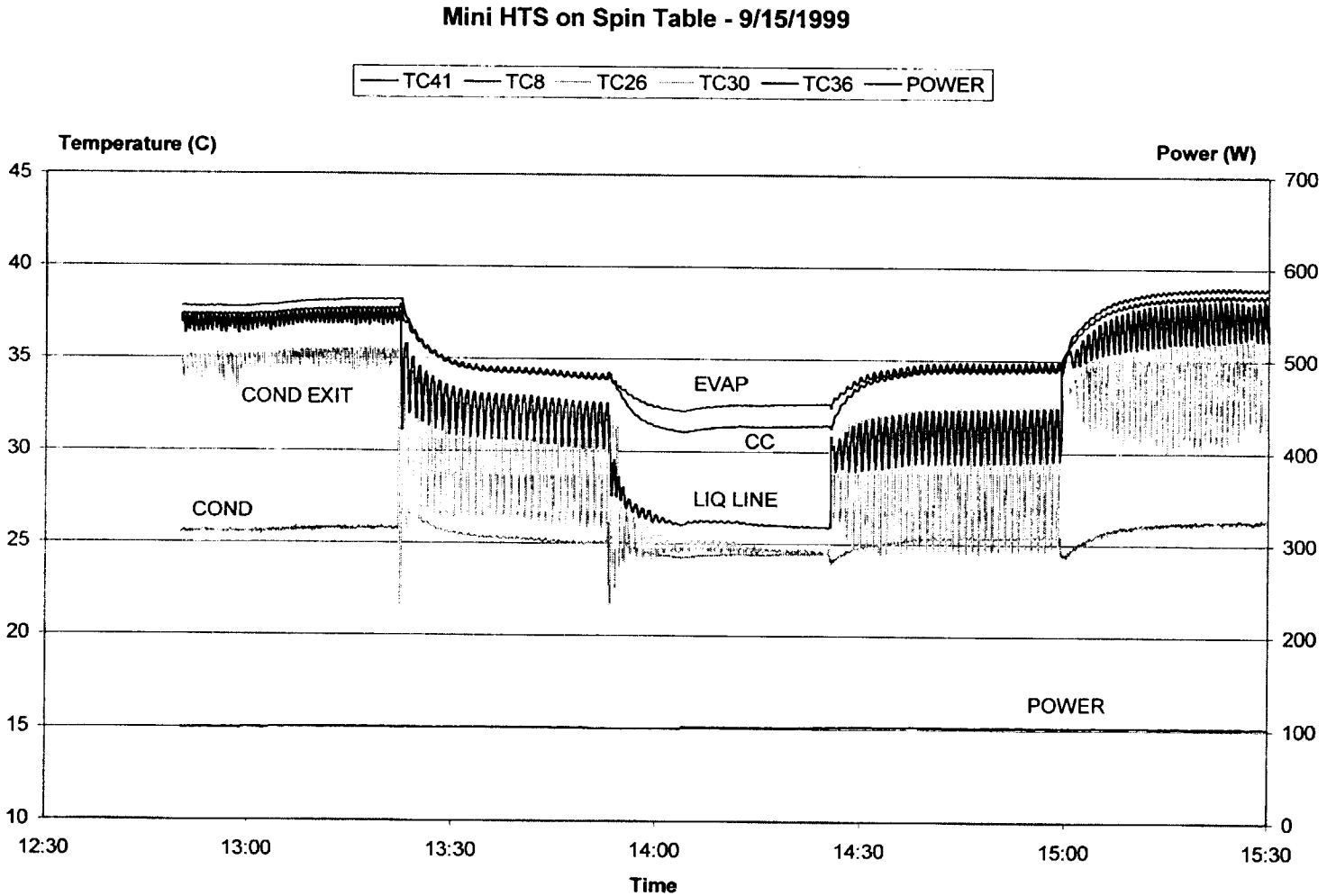
Effects of Acceleration on Temperature Oscillation and Hysteresis

- Accelerations can change the loop operating temperature even when the heat load and sink temperature are fixed. This is because the fluid redistributes within the loop and change the energy balance in the CC.
- When the vapor/liquid interface reaches the condenser outlet, operating temperature will oscillate. Accelerations may cause the interface to extend to or retreat from the condenser exit, causing temperature oscillations to appear or disappear.
- The operating temperature and magnitude of oscillation may change after an acceleration, resulting in a temperature hysteresis.

Temperature Oscillation/Hysteresis vs Spin Rate
CC on Outer Edge/30rpm/60rpm/30rpm/CCW/100W (1 of 4)



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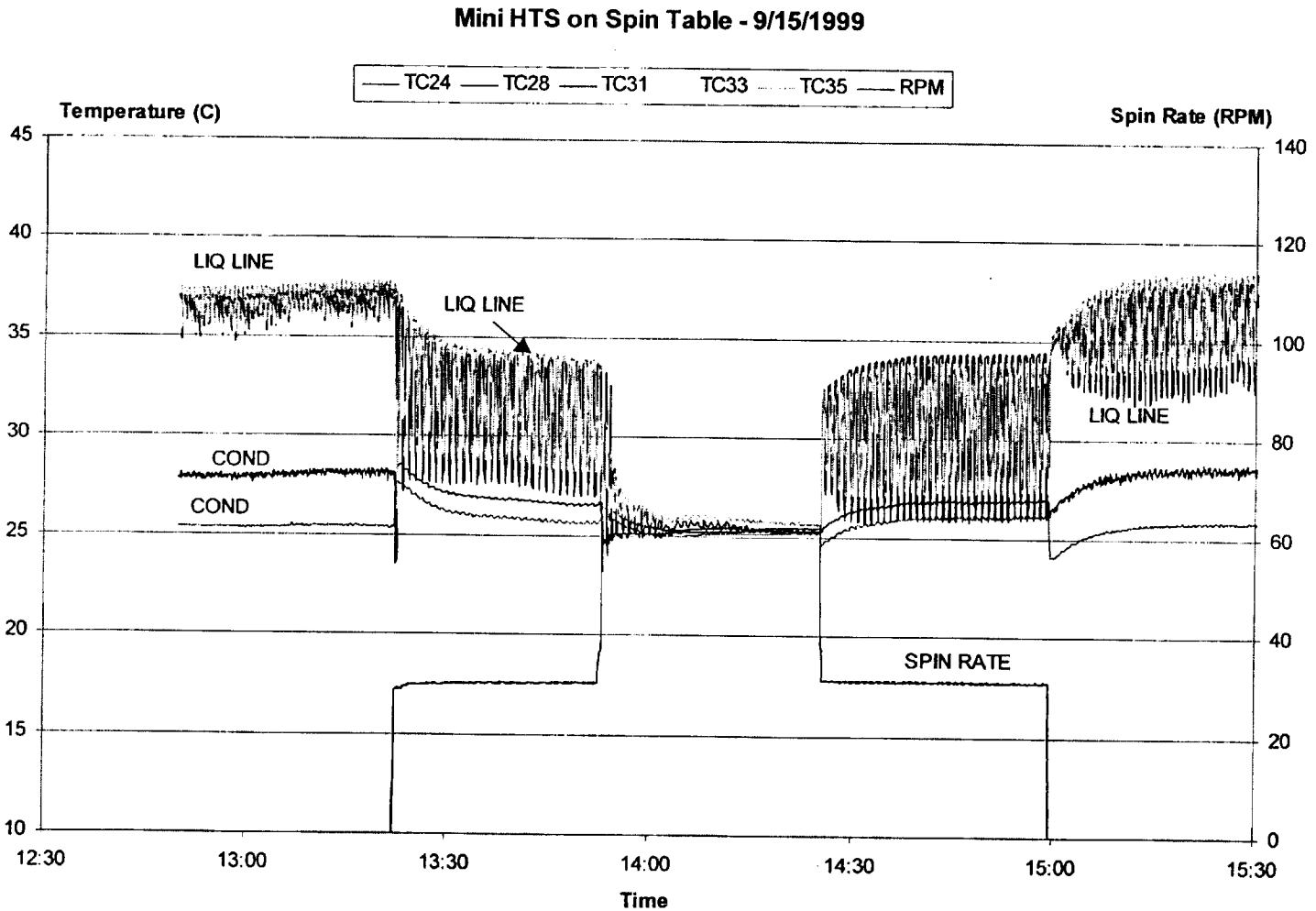
Temperature Oscillation/Hysteresis vs Spin Rate
CC on Outer Edge/30rpm/60rpm/30rpm/CCW/100W (2 of 4)



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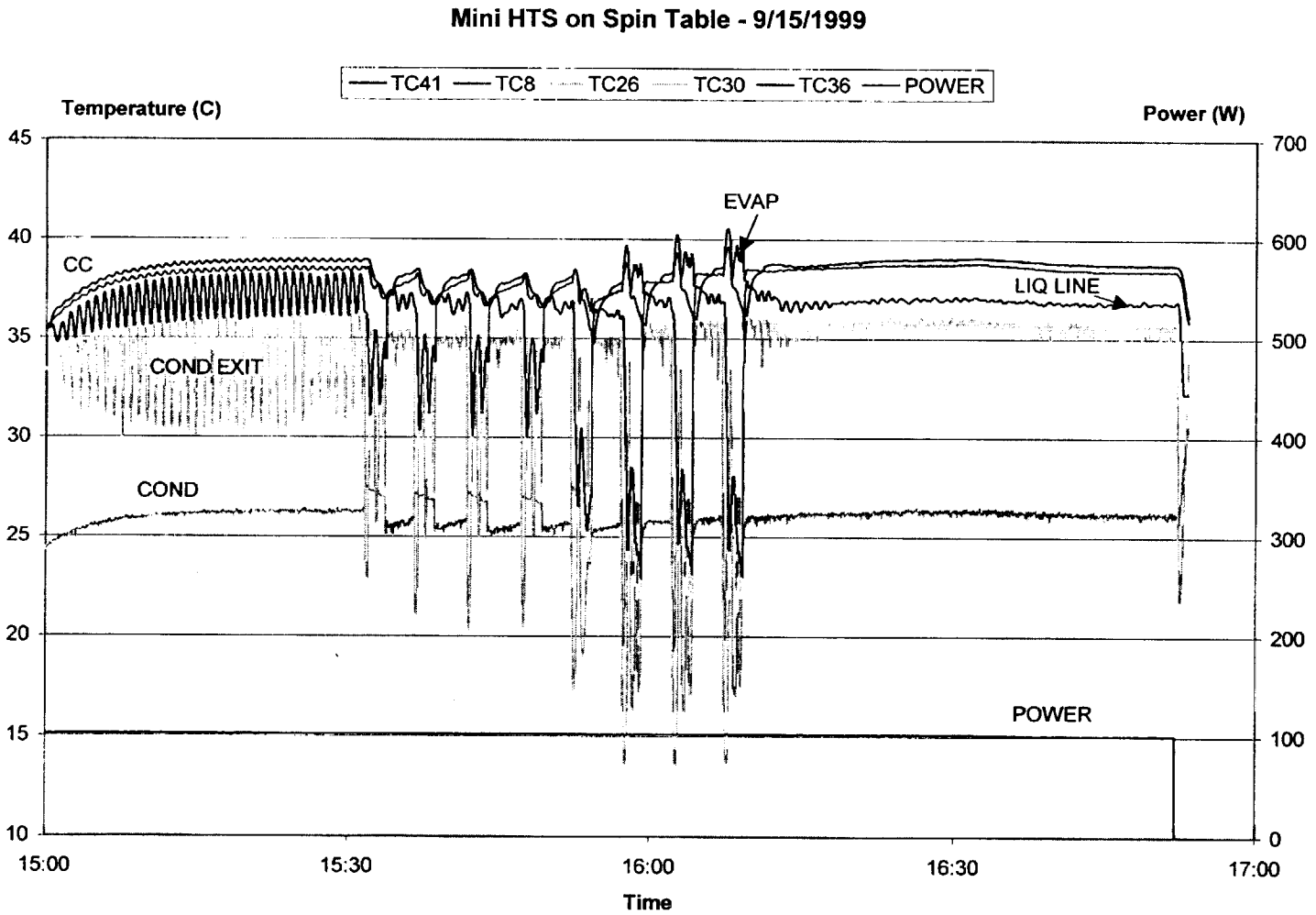
Temperature Oscillation/Hysteresis vs Spin Rate
CC on Outer Edge/30rpm/60rpm/CCW/100W (3 of 4)



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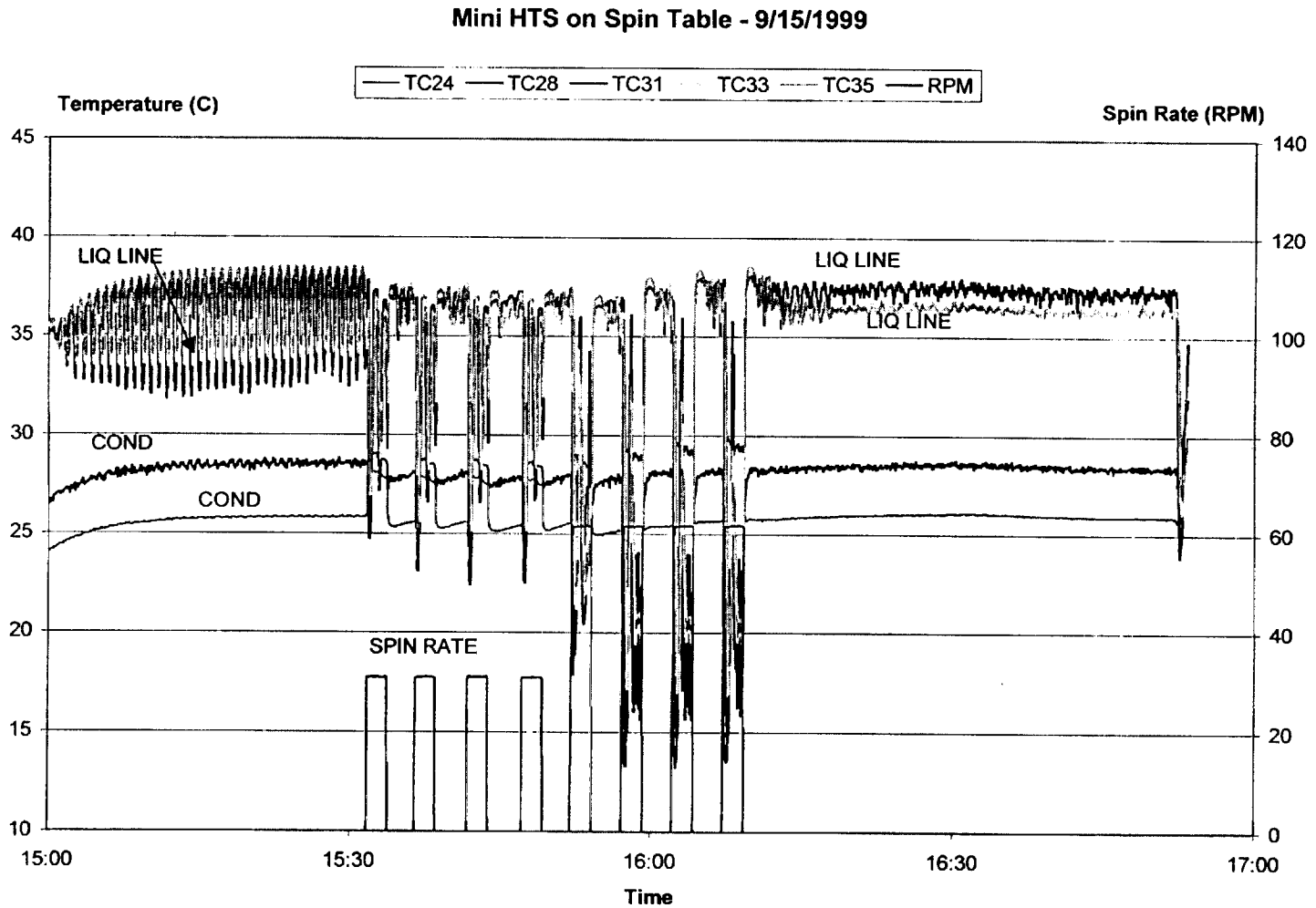
Temperature Oscillation/Hysteresis vs Spin Rate
CC on Outer Edge/30rpm/60rpm/CCW/100W (4 of 4)



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Summary

- The LHP demonstrated robust operation under various operating conditions and different patterns of accelerations.
- Accelerations affects the loop operation through its influences on the fluid distribution among the evaporator, CC and condenser.
  - Temperature overshoot during start-up
  - Increase or decrease in the operating temperature
  - Temperature oscillation
  - Temperature hysteresis